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   Cambridge CB4 0WS

   Patents ADP number *(if you know it)* — 8113870002

   If the applicant is a corporate body, give the country/state of its incorporation — England

4. Title of the invention — LOUDSPEAKER

5. Name of your agent *(if you have one)* — Akram K. Mirza

   "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

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   Patents ADP number *(if you know it)* — 8243347002

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Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application	Date of filing *(day / month / year)*

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:*
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   b) there is an inventor who is not named as an applicant, or
   c) any named applicant is a corporate body.
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Claim *(s)*	2
Abstract	1
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Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	
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Any other documents *(please specify)*	

11. I/We request the grant of a patent on the basis of this application.

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Date 17-SEP-2002

12. Name and daytime telephone number of person to contact in the United Kingdom — Akram K. Mirza — 01223-422290

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P160-GB

LOUDSPEAKER

FIELD OF THE INVENTION

The present invention relates to loudspeakers, particularly loudspeakers suitable for generating audible sound of HiFi quality. More specifically, it relates to planar loudspeakers. Even more specifically it relates to planar loudspeakers having a sound generating element or diaphragm with an electro-mechanical transducer mounted thereon.

BACKGROUND OF THE INVENTION

The reproduction of audio recordings has been until very recently dominated by voice-coil driven cone-shaped diaphragms mounted on boxes or similar enclosures. Alternative technologies using planar loudspeakers have been struggling to become more wide spread either due to high costs, as, for example electrostatic loudspeakers, or due to the poor quality of the sound generated. Particularly, piezoelectrically driven loudspeakers have been almost exclusively used for low sound quality devices, such as greeting cards, buzzers, telephone speakers and the like.

Planar and piezoelectric loudspeakers are described in many prior art documents including United States patent nos. 4,654,554; 4,969,197; 5,514,927; 5,780,958; 5,736,808; 6,078,126; 6,091,181; 6,198,206 and the published international patent application WO-9203024.

The known speakers include bending-wave loudspeakers ("BWL"), also referred to as flexural wave or distributed mode loudspeaker, having a thin extended flexible panel that is driven by an actuator close to the centre (but not usually at the centre) in a direction orthogonal to the plane of the panel so as to induce bending out of the plane of the panel.

Bending waves travel across the panel surface and are partially reflected by the impedance discontinuity at the panel edges. Multiple reflections occur and dense wave patterns form on the surface. If the panel is immersed in a fluid, such as air, then sound waves are generated in the fluid and the device may be used as a loudspeaker.

Conventional BWL use magnetic or piezoelectric actuators to produce the bending waves. A magnetic moving-coil actuator has very asymmetric properties - its moving-coil has a very low mass and when driven by an electric current experiences a driving force relative to the very much heavier magnet. When actuated the coil usually moves with high velocity and the magnet with very low velocity. This asymmetry is usually emphasised by clamping the magnet assembly to the nominally fixed frame of the machine containing the actuator.

In a conventional magnetically driven BWL the magnet of the moving-coil actuator is often fixed to the nominally static frame of the loudspeaker, while the moving coil is attached to the flexible panel to be driven. Reaction forces are thus between the panel and the loudspeaker frame. In an alternative arrangement, the moving-coil is attached to the flexible panel and the magnet assembly is allowed to hang free coupled only by the suspension of the actuator. Upon driving the actuator, the high inertia of the magnet assembly is used to provide reaction force to the coil and panel. In this latter configuration, the loudspeaker need have no frame as such, though some means of support of the whole assembly is generally provided to allow floor or wall mounting and to improve the durability of the device.

In piezoelectrically driven BWL the actuators are generally symmetrical and the inertial mass of the actuators available

are generally inadequate to provide sufficient reaction force and a mounting frame becomes required if the panel is to be adequately driven. Such a mounting frame generally contributes nothing to the sound output, and simply adds weight and cost to the device. If it is to not reduce the efficiency of driving of the panel, the frame needs to be adequately stiff and lossless - these properties are incompatible with very low weight, low mechanical impedance and low cost.

In conventional BWL at medium to high frequencies, the radiation from each face of the panel adds constructively as approximately random-phase radiation, the two radiating surfaces producing a total sound power roughly p2 [?] as big as the contribution from one side alone. However, at low frequencies, where the dimensions of the panel become comparable to the wavelength of the bending waves within the panel, the panel starts to act effectively as a piston-radiator and at these low frequencies the phase of the radiated sound produced by one side of the panel is necessarily opposite to that produced by the other side of the panel. A consequence is that such low frequency radiation as occurs tends to mutually cancel itself in the far field leading to poor low frequency performance overall and, therefore, require a housing or cabinet.

Therefore it is seen as an object of the current invention to provide a panel loudspeaker with improved sound reproduction, particularly at lower frequencies. It is seen as another object of the invention to improve piezoelectrically driven panel loudspeakers.

SUMMARY OF THE INVENTION

According to a first aspect the invention provides a balanced

form of bending wave loudspeaker. A low mass and low impedance electroactive actuator, preferably a piezoelectric actuator such as the Helimorph™ , is used as the actuator to produce bending waves in order to produce sound. A balanced configuration is proposed eliminating the requirement for a relatively massive mounting frame.

The balanced configuration is preferably achieved by a pair of approximately parallel thin extended flexible panels spaced apart by a small distance, sufficient to allow the actuator (or actuators in a multiply driven BWL) to be placed between their co-facing surfaces. To be balanced the parallel panels are closely impedance matched within the surrounding fluid, such that the energy of the actuator is transferred to both panels in essentially equal amounts. A preferred configuration that achieves impedance matching with is to use two identical or essentially identical panels.

The position chosen for placement of the actuator(s) relative to the edges of the panels can follow the well-known and generally accepted positioning rules for BWL, e.g. one such position being close to the centre, at 3/7 of the length of the panel and 4/9 of its width. One end of each actuator is fixed to the first panel and the other end of each actuator is fixed to the second opposing panel, the actual relative positions being determined by the actuator geometry, but in general the two ends are fixed at points on the two panels which are roughly opposite each other. The nature of the actuator is chosen such that its length in a direction orthogonal to the plane of each of the panels changes when driven electrically, and in general the actuator will both lengthen and shorten under electrical drive.

In a variant of the above arrangement, the spacing between the

panels may be reduced to less than the clearance height of the actuator. For example, the actuator can be partially housed within the thickness of one or both of the panels by removing the panel core material adjacent to the actuator. The actuator may then be attached to the inner of one or both panels rather than to the panel surface. The two panels can then be positioned such that that the gap between them becomes very narrow, particularly when combined with a actuator assembly of reduced height (e.g. a single turn flat Helimorph™). Even closer spacing of the two panels can be achieved by forming the outer face of the diaphragms as shallow protrusion, e.g. dome shaped, at the location of the actuator.

The panels are preferably planar with a flat or curved shape and are preferably made of a low-weight material with a high stiffness. Such materials are known and often include a composite structure. Known composite materials include for example a layer of honeycomb structure made from resin paper or light metals enclosed in two sheets of reinforced resin. Polymer variants of this structure are also available, such as foamed-core boards.

At suitable points of minimal bending displacement ("nodal points") where the amplitude of bending waves is lowest in normal operation of the BWL, fixings and spacers may be attached that fix one panel relative to the other (locally) and determine their precise mutual separation. Such fixing may be either rigid (e.g. bolts with rigid spacer pieces between the panels) or compliant (e.g. foamed polymer pads providing nominal spacing and which may be bonded to the panel surfaces, or alternatively also used as standoffs for fixing pins holding the two panels apart, but acoustically decoupled from the panels by the foam polymer. Suitable fixing points depend on the properties of the panels and include, in the case of

rectangular panels positions close to their edges but not at the edges. Suitable positions are within a distance from the edge of 1/9 of the width or length, respectively. It may be beneficial to reinforce these attachment points.

Therefore, in a preferred variant the two panels are fixed to each other by only a limited number of point connections leaving a continuous, connected fluid-filled space or volume between the panels. The edges of the panels are left to move freely, or, if a sealing connection to the surrounding is required, connected with highly compliant material.

Another preferred design consideration aims at reducing the distance between the two panels. In general, this distance will be determined by the size of the actuator placed between them. However, given the current size of such actuators a spacing of less that 10mm, or even less than 5mm or even 2mm can be regarded feasible.

A lower limit of the distance is defined by twice the peak amplitude of the panels, independent of whether it oscillates in a bending or in a pistonic mode, to avoid a contact between the two panels in operation. Also the fluid between the panels should move without high resistance within the gap. These considerations lead to an optimal distance between the inner faces of the panels of around 1 or 2mm to 4mm for most loudspeaker applications.

Though potentially various designs of piezoelectric transducer may be suitable for the purpose of the present invention, the benders described, for example, in the international patent application WO-0147318 are particularly well suited for this application which demands a large displacement of the actuator in order to generate high sound pressure levels. As mentioned

above, the Helimorph™, a twice-coiled piezoelectric bender, is probably the best actuator for the proposed application. However, in principle any low mass and low impedance actuator may be used to drive the loudspeaker panels.

When the actuator(s) is driven electrically, the two panels are driven relative to each other in a direction out of the plane of each panel producing bending waves in the panel, and as before, if the panel is immersed in fluid, e.g. air, sound waves are emitted. However, in this case, the outer surfaces of both panels (i.e. the unopposed faces) will be driven in-phase with each other (i.e. both will be driven outwards or inwards simultaneously), so that at low frequencies their acoustic outputs will add in-phase and not mutually cancel. Clearly however, the two internal surfaces of the panels will also radiate in-phase with each other and out of phase with the outer surfaces of the panels and to the extent that the space between the panels is coupled to the surrounding fluid, some overall mutual cancellation will still occur.

The load impedance seen by the driving actuator(s) will be approximately one half that produced had just one of the panels been driven in the conventional way relative to a stiff or massive frame or inertial reaction mass. This lowering of load impedance facilitates the task of matching a given panel material to a low-impedance actuator such as a Helimorph™.

Such a balanced BWL has several advantages over current conventional BWL designs in that there is no requirement for a heavy inertial reaction mass for the actuator. Also, a stiff and necessarily relatively massive mounting frame to provide a reaction load for the actuator can be dispensed with. The loudspeakers in accordance with the above aspects of the

invention can be made very thin. They have an improved low-frequency output and a reduced load impedance on the actuator.

These and other features of the inventions will be apparent from the following detailed description of non-limitative examples making reference to the following drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1 is a cross-sectional view of a known panel loudspeaker;

FIG. 2A is a cross-sectional view of an embodiment of the present invention;

FIG 2B is a perspective view of the embodiment of FIG. 2A;

FIG. 3 is a cross-sectional view of another embodiment of the present invention; and

FIG 4 is a cross-sectional view of a further embodiment of the present invention.

DETAILED DESCRIPTION

A number of different bending wave speakers are known. In FIG. 1, there is shown an example of a piezoelectrically driven loudspeaker **10** with drivers **11** integrated into a diaphragm **12** that is composed of several layers **121** to **124**. The drivers 11 are mounted onto small projection members **125** within a recessed space **126** within the two resin foam layers **122**, **123**. By assembling the two layers **122**, **123** a single diaphragm **12** with integrated drivers **11** is produced. When activating the

drivers 11, the diaphragm **12** emits sound from both main surfaces **121**, **124**. Through elastic supporting members **13**, the diaphragm **12** is mounted onto an outer frame structure **14**.

In an example in accordance with the present invention as shown in FIG.2, the loudspeaker **20** includes two flat panel diaphragms **22**. For stability and maximum stiffness at minimum weight, each diaphragm **22** has a honeycomb core layer **221** enclosed between two cover layers **222**, **223** of carbon-fibre reinforced resin. Both diaphragms are essentially identical rectangles of 25cm by 35cm. The two diaphragms **22** are connected and spaced apart approximately 4mm by rivets **23** leaving an enclosed volume **26** filled with air. A piezoelectric driver **21** is mounted between the opposing inner faces **223** of the two diaphragms **22** such that one end of the actuator **21** is in a force-transmitting connection with one diaphragm whilst the other end of the driver is connected to the opposite diaphragm, again in a force-transmitting connection. The driver **21** is a Helimorph™ with the minor helix turned by approximately one full turn. Leads **211** are supplied to apply a signal to the actuator **21** during operation. The actuator is preferably mounted on studs (not shown) to facilitate manufacturing of the device.

The perspective view of FIG. 2B has a cut-away section showing the driver **21** in a slightly off-centred position at 3/7 of the length of the panel and 4/9 of its width. The rivets **23** are placed at a distance of approximately 1/9 of the full length or width, respectively, of the panel diaphragms **22**, leaving the edges free to follow the bending motion induced through the actuator **21**. However, the rivets may be placed at other positions that do not interfere with the bending wave motion.

The loudspeaker **20** can be suspended from wires or stands (not shown) attached for example to the rivets **23** or the edges of the loudspeaker.

In another example of the invention, shown in FIG. 3, the two diaphragms **32** of the loudspeaker **30** are brought closer together compared to the previous example. As the spacing between the two panels is reduced to less than the effective height of the actuator **31**, its ends are placed within recess sections **326** formed by machining away part of the core layer **321** of both panels **32**. Optionally, these recessed sections of diaphragm are reinforced. As above, the two diaphragms **22** are connected and spaced apart by rivets **33** leaving an enclosed volume **36** filled with air. The driver **31** is a Helimorph™.

In the example as illustrated by FIG. 4, the actuator **41** is housed within two concave inserts **425** in each of the diaphragms **42**. At their rim, the inserts **425** are firmly connected to the respective diaphragms **42**. In this example small, compliant foamed pads **43** are glued to the inner faces **423** to maintain a default spacing between the two diaphragms **42**. The driver is a Helimorph™, however the configuration enables the use of other bigger drivers, such as stacks of recurved piezoelectric benders and so-called moonies.

CLAIMS

1. A balanced bending wave loudspeaker.

2. A balanced bending wave loudspeaker comprising a first and second diaphragm and at least one actuator coupled with a first end to said first diaphragm and a second end to said second diaphragm to simultaneously excite bending waves in said first and second diaphragm.

3. The loudspeaker of claim 2 wherein the first and second diaphragm have essentially equal impedance.

4. The loudspeaker of claim 3 wherein the first and second diaphragm are essentially equal.

5. The loudspeaker of claim 2 or 3 wherein the diaphragms are flat or curved planes.

6. The loudspeaker of claim 2 wherein the diaphragms are arranged in parallel with a continuous fluid filled gap between them.

7. The loudspeaker of claim 6 wherein the diaphragms are separated by less than one tenth of their smallest lateral dimension.

8. The loudspeaker of claim 6 wherein the diaphragms are separated by a medium distance of less than ten millimetres.

9. The loudspeaker of claim 2 wherein the actuator comprises an electro-active material.

10. The loudspeaker of claim 9 wherein the actuator is a piezoelectric actuator.

11. The loudspeaker of claim 10 wherein the actuator is a coiled-coil piezoelectric bender.

12. The loudspeaker of claim 2 wherein the height of the actuator exceeds a minimal spacing between the first and the second actuator.

ABSTRACT

A bending wave loudspeaker is described with two closely spaced diaphragms simultaneously driven by the two ends of an actuator. By balancing the impedance load of both diaphragms on the actuator both diaphragm radiate in phase and hence improve low frequency reproduction.

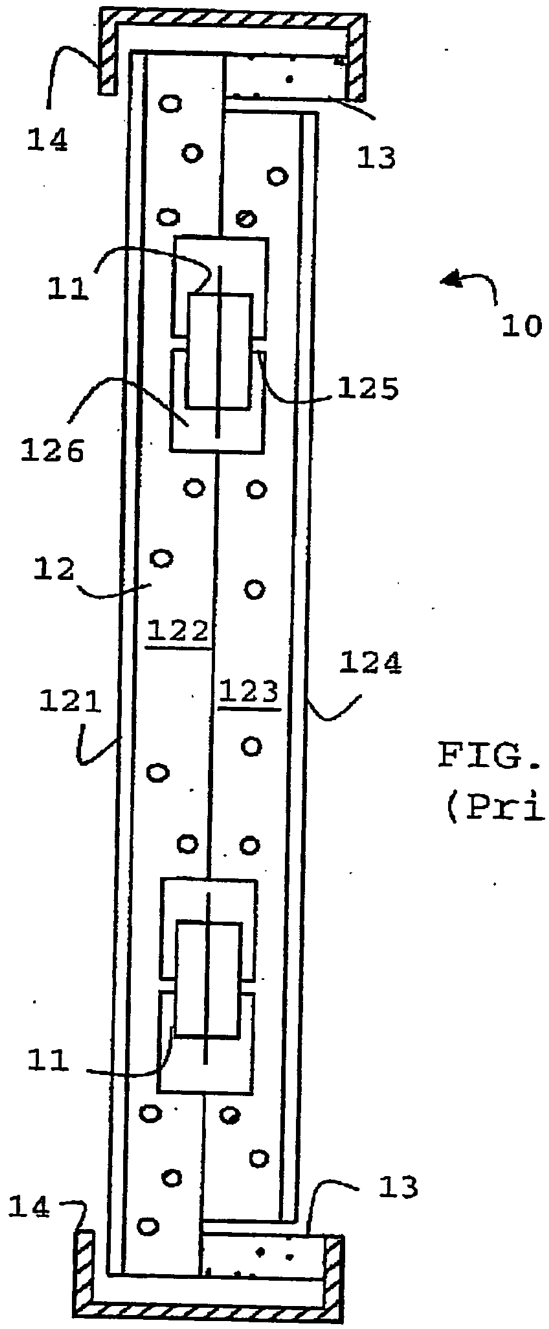

FIG. 1
(Prior Art)

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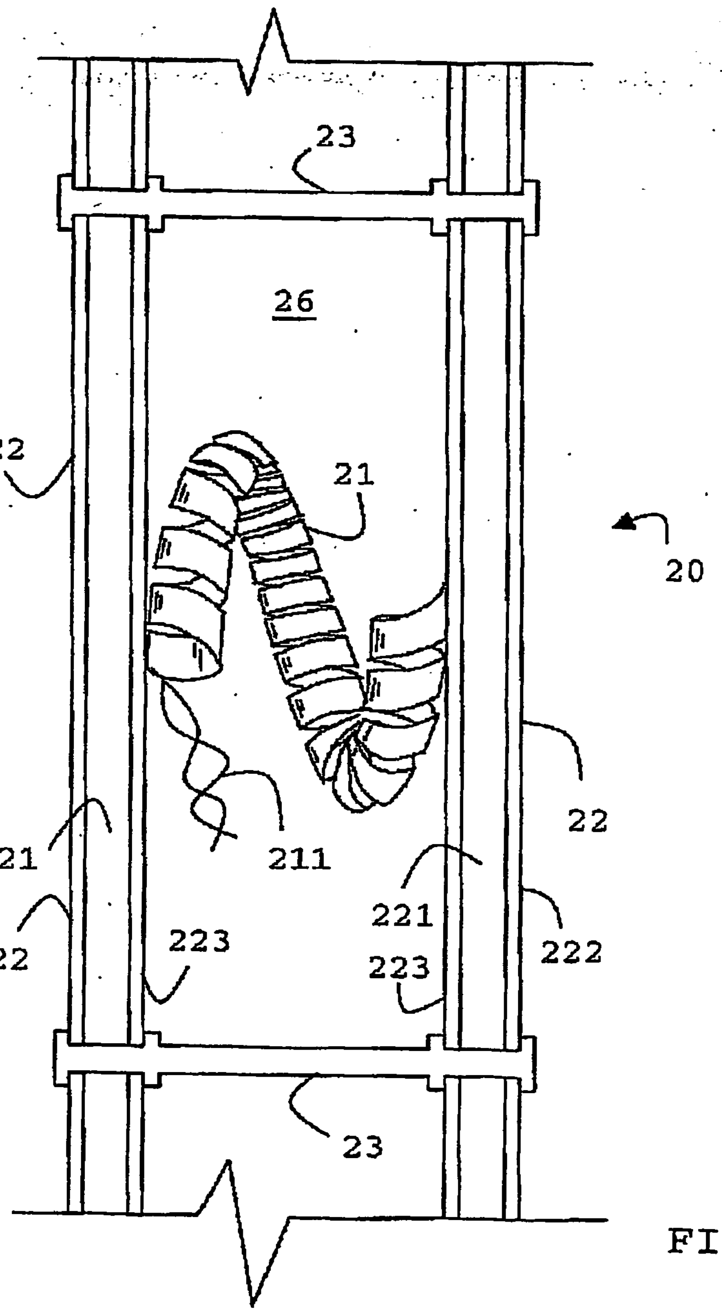

FIG. 2A

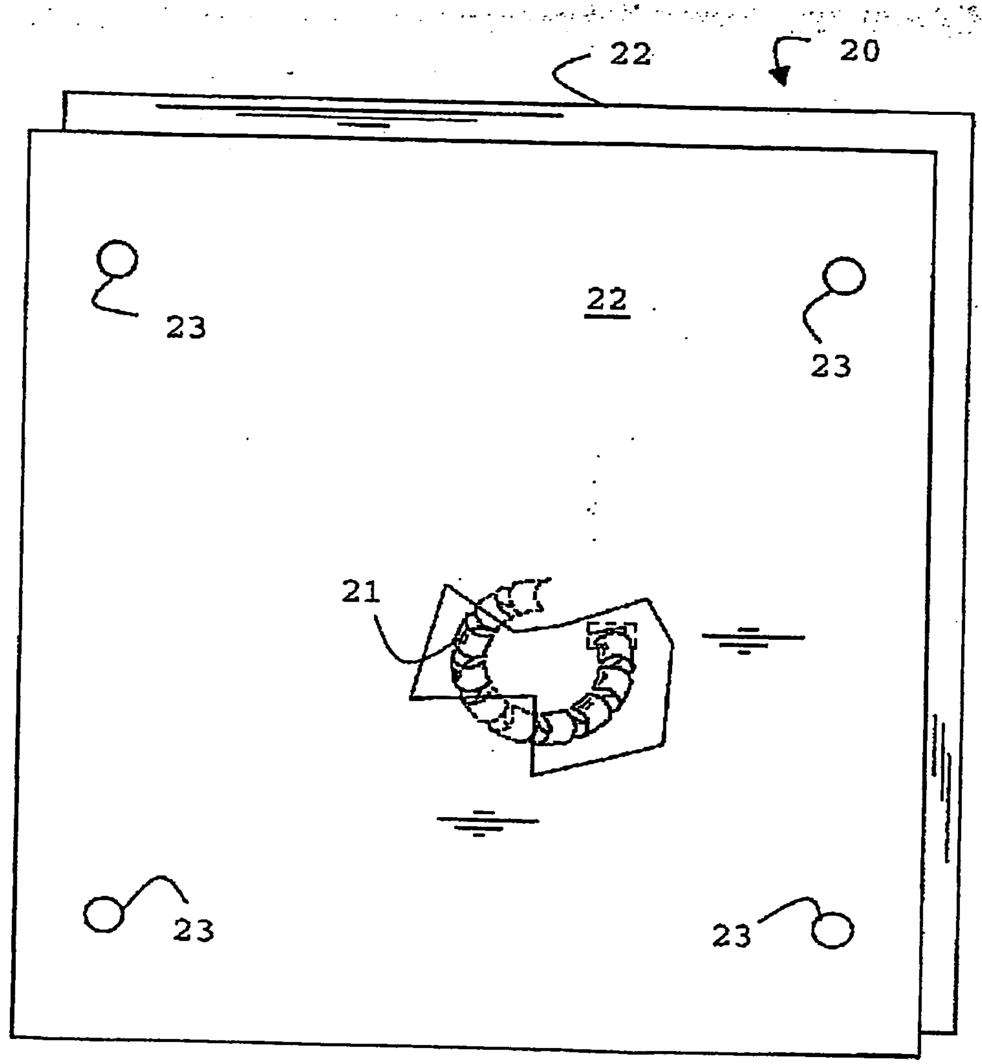

FIG. 2B

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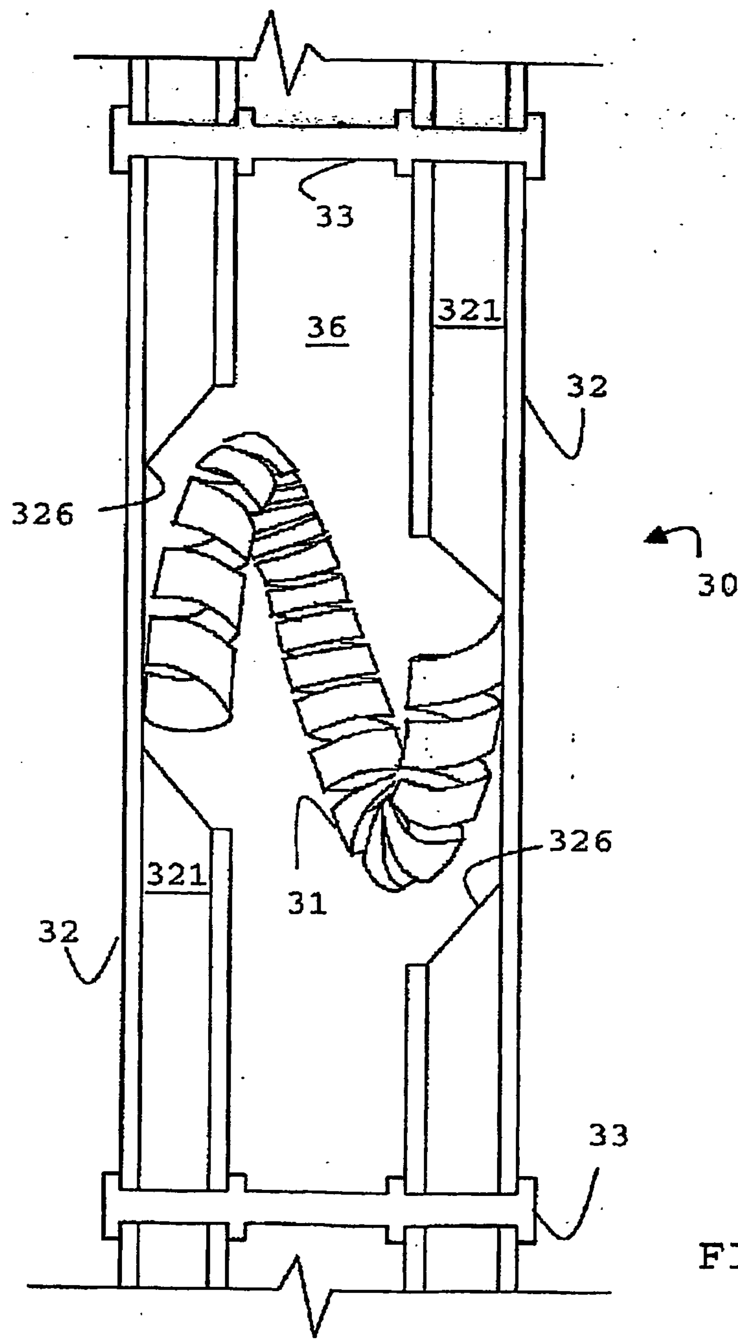

FIG. 3

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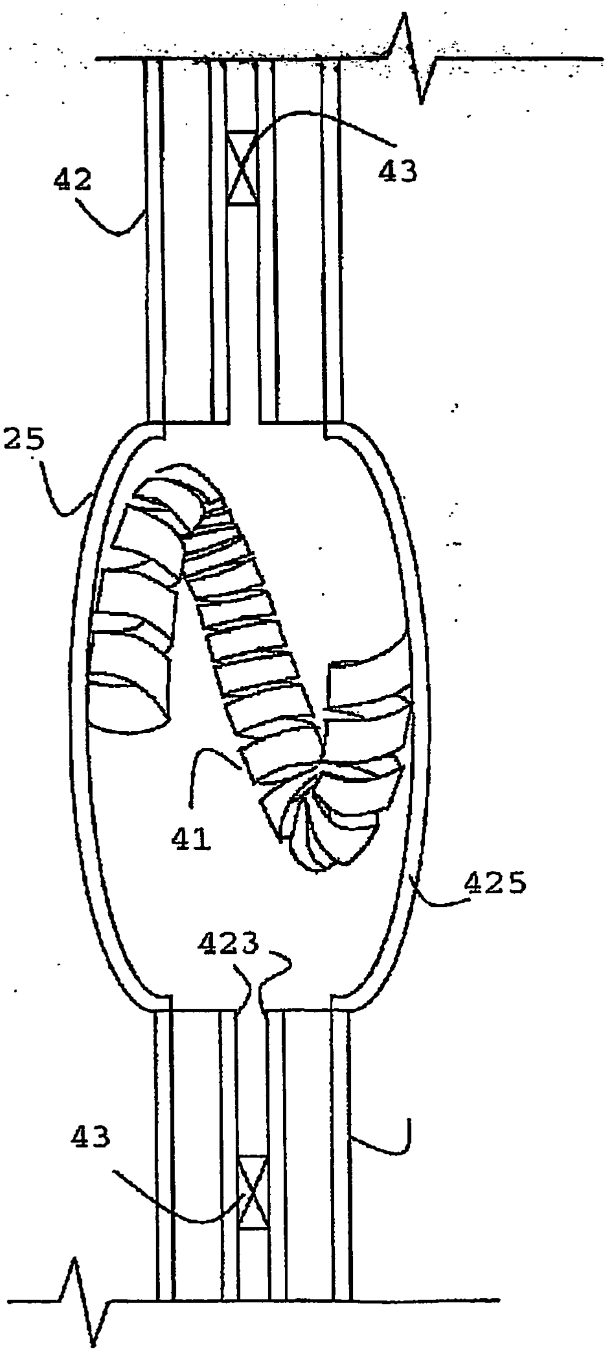

FIG. 4

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